Mechanical Properties and Surface Functionality of RRR Nb

Workshop on RRR Niobium at Fermi Lab May 2005
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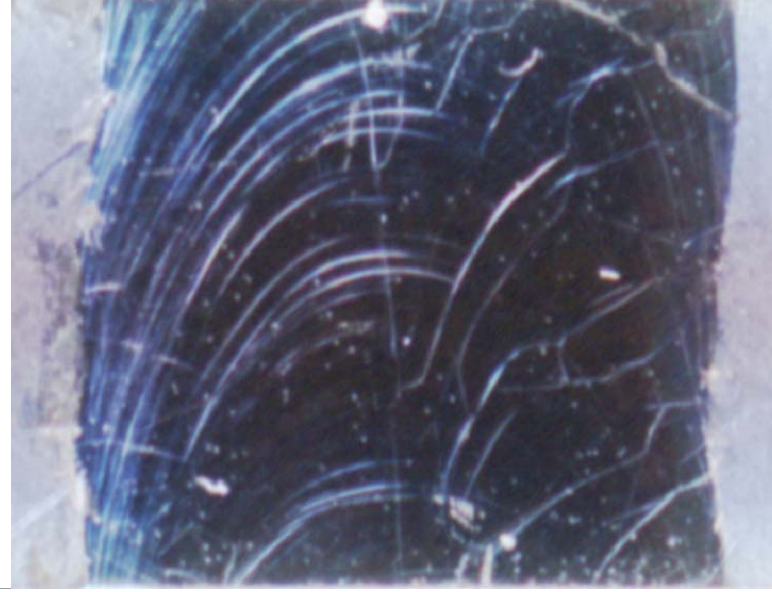
- Nb for SRF cavities needs to be formable
  - BCC metals are highly formable with deep drawing
  - due to high R values from {111} // sheet normal
- SRF cavities must be welded together and be dimensionally stable
  - Welds have different mechanical and surface properties from parent material
- Surface properties are crucial for function
  - Etching to make smooth surface depends on etching rates of different crystal orientations, forms ledges
  - Surface crystal orientations matter

Weld has a large grain size with surface grooves or ledges, grain boundaries ⊥ to solidification pool ridges

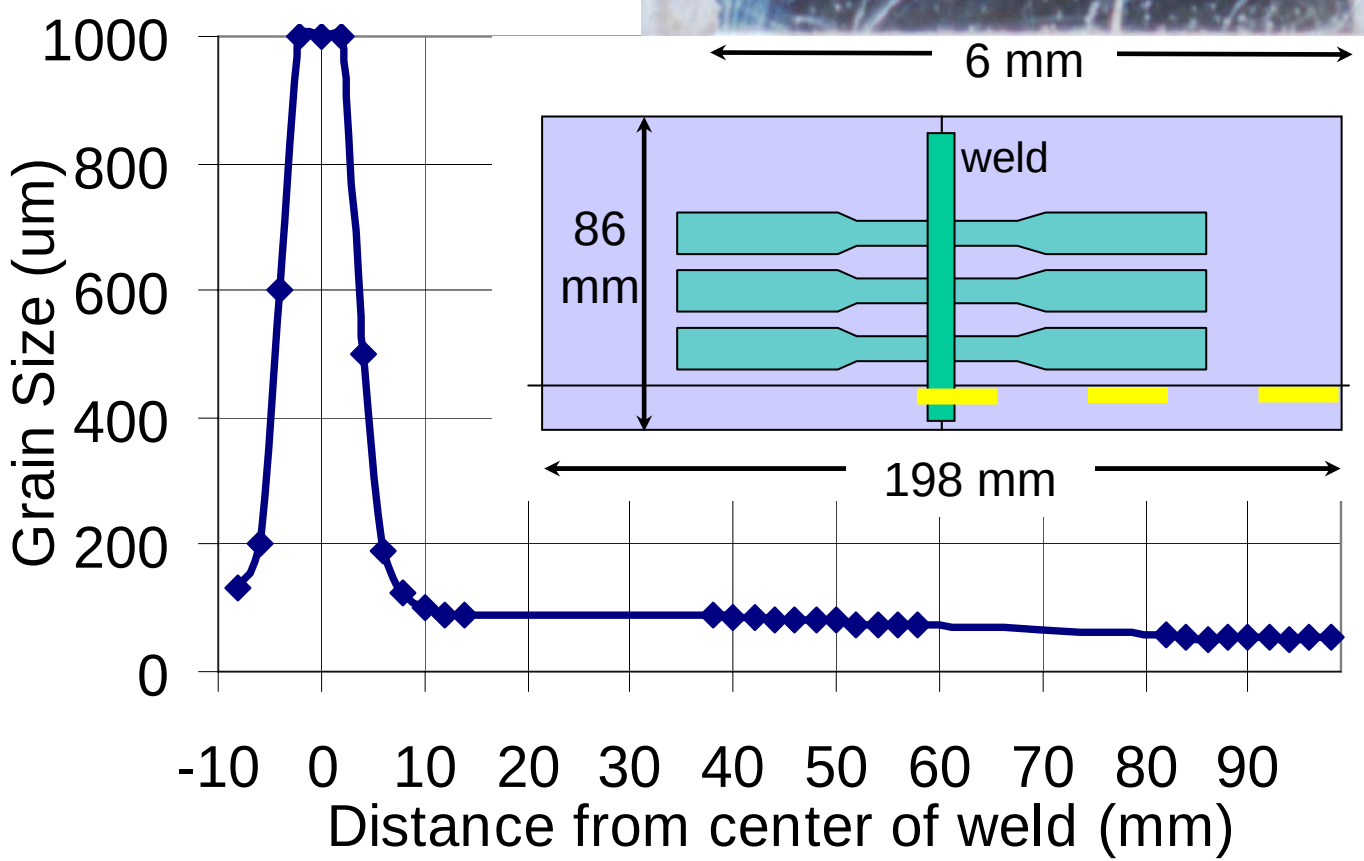


Grain Size

6 mm wide weld fusion zone ~ 1 μm

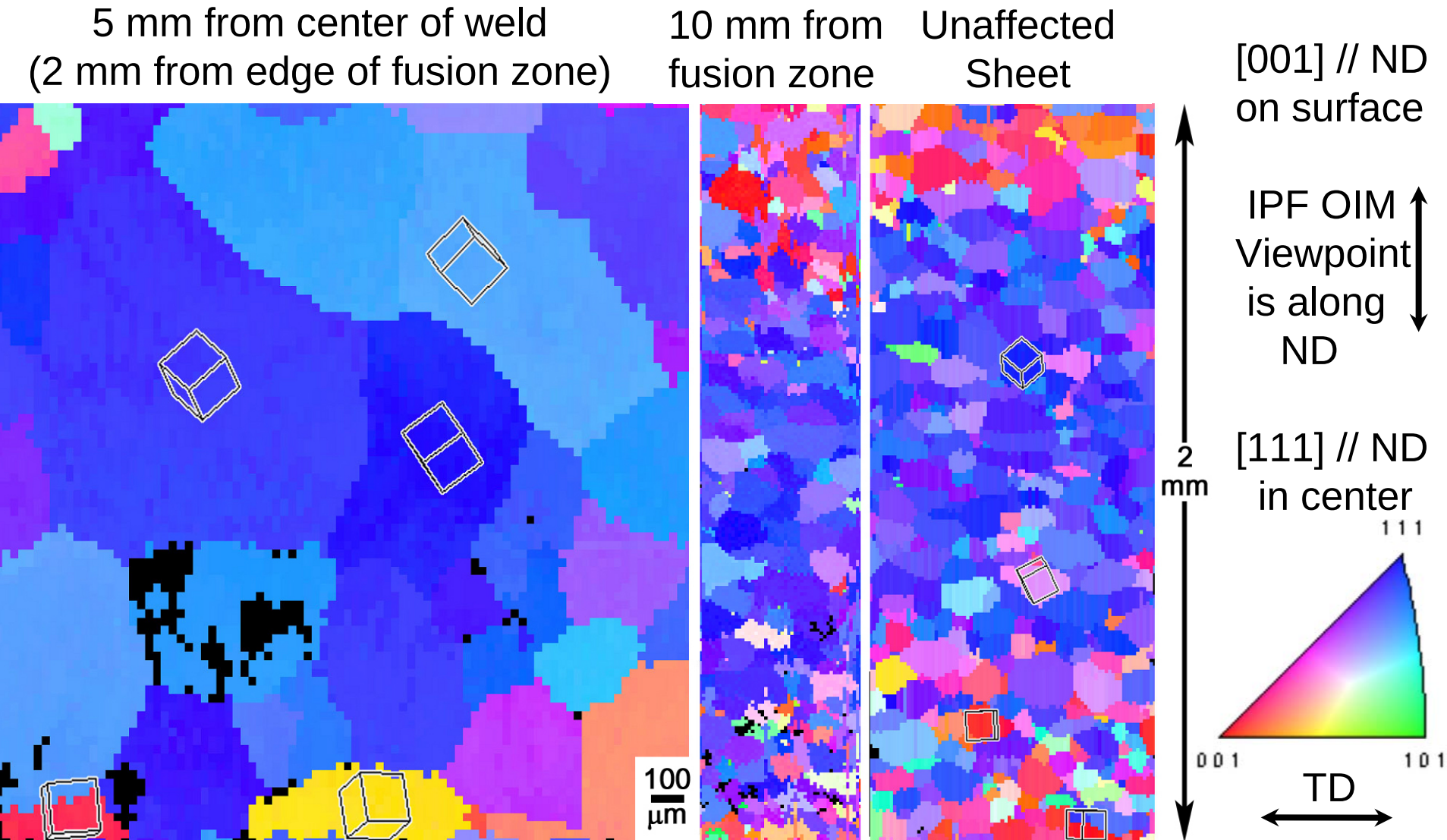
Heat Affected Zone up to 40 mm away ~ 100 μm

> 80mm away ~ 50 μm, same as parent material



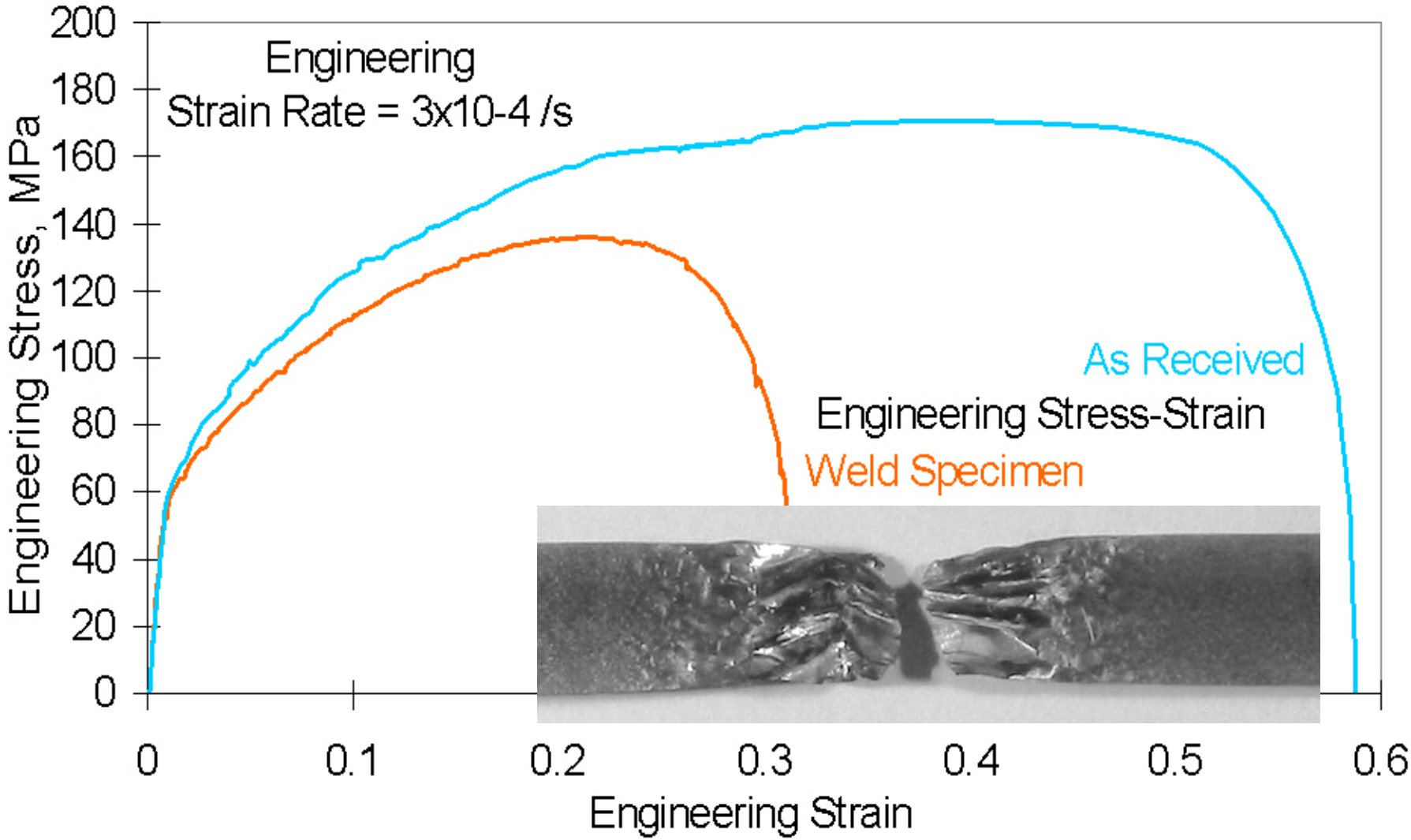
Orientation Imaging Microscopy shows microstructure and texture information together

Texture in weld is similar to parent material



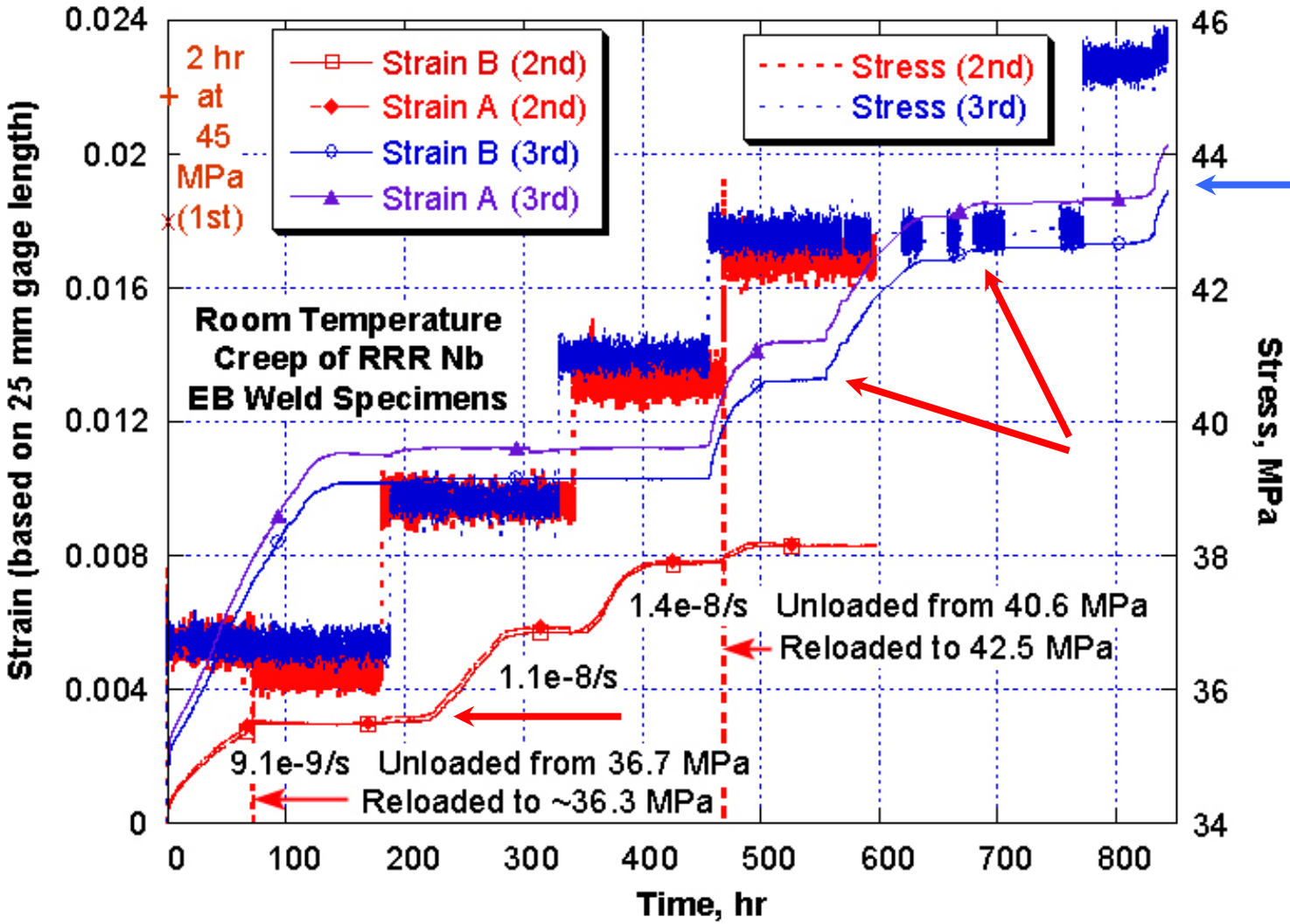
Engineering Stress-Strain shows degraded tensile properties in weld specimen

- Maximum stress is 140 MPa, 10-20 MPa less than normal material
- Specimens all failed between center and edge of weld



Three Weld Creep specimens (Transverse Direction)

1. Loaded directly to 45 MPa ε=0.018 2 hr
2. Loaded / Unloaded 37- 43 MPa ε =0.008 600 hr
3. Step Loaded 37- 45 MPa ε = 0.02 800 hr

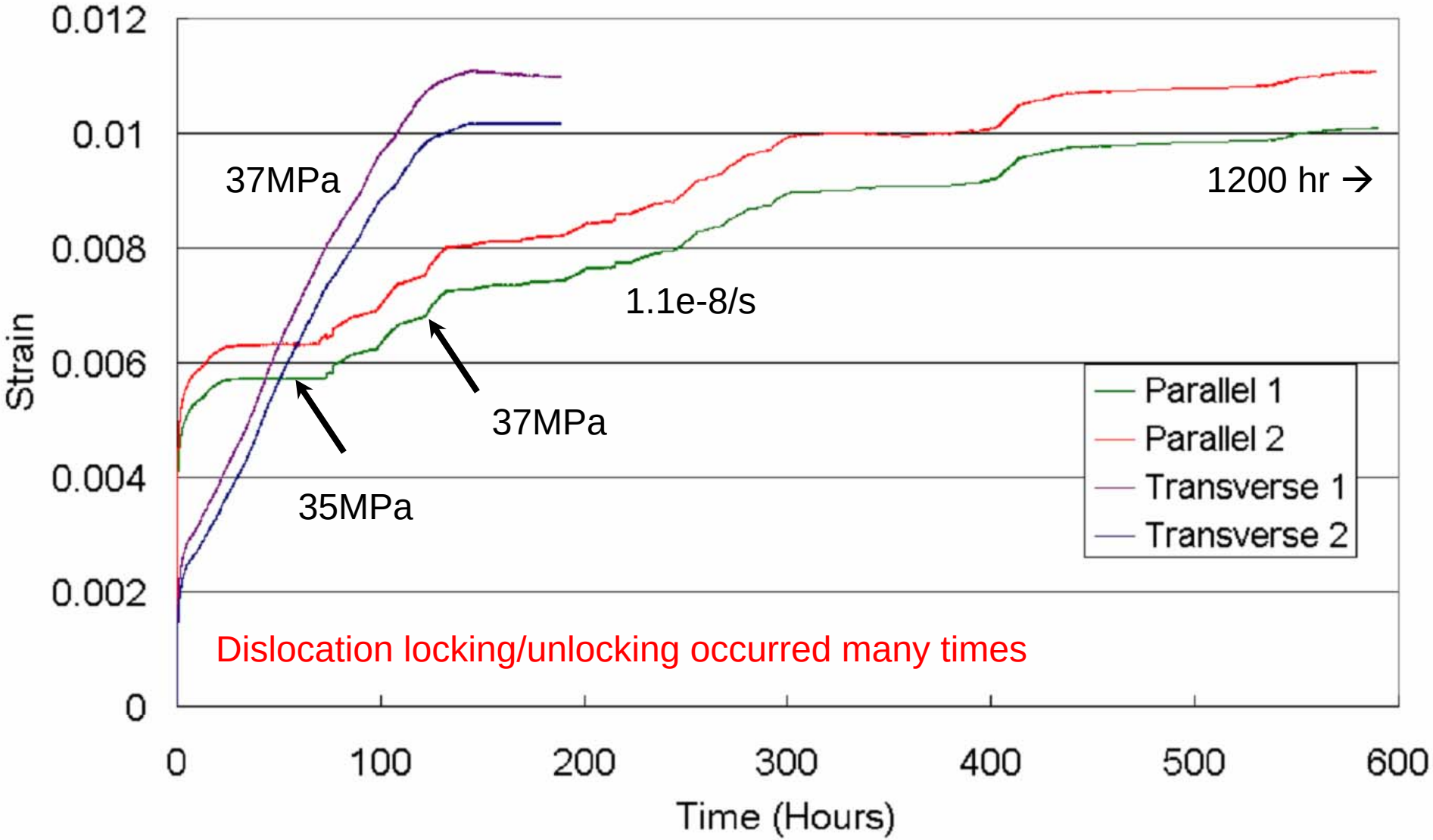


Different strains imply that one side deformed more than the other side

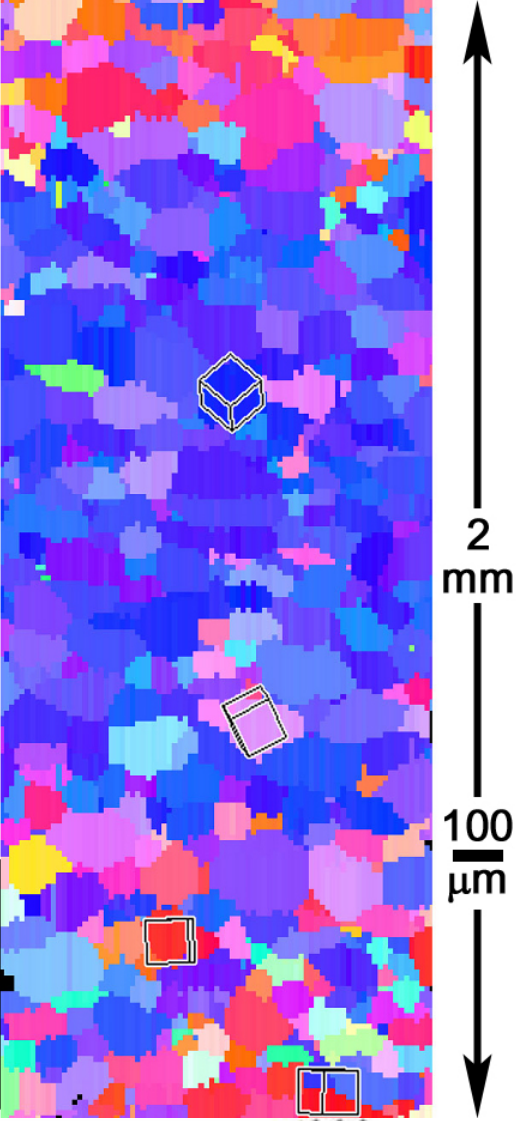
Dislocation unlocking occurred to allow large strain increments at constant load

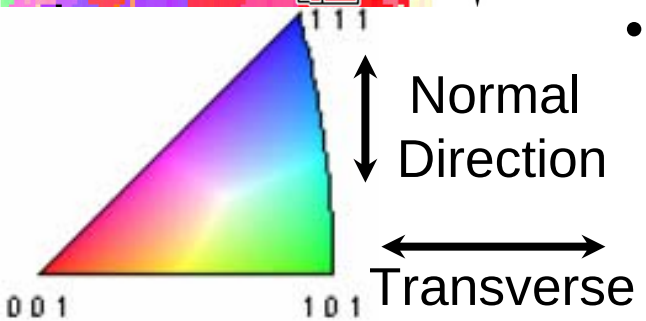
Not very dimensionally stable!

Room temperature weld creep differs in details between rolling and transverse directions, but gets to a similar strain at the same stress



Commercially available 2 mm recrystallized Nb sheet has strong <111> fiber texture, and some <100> fiber on surface – Desirable? Yes and No



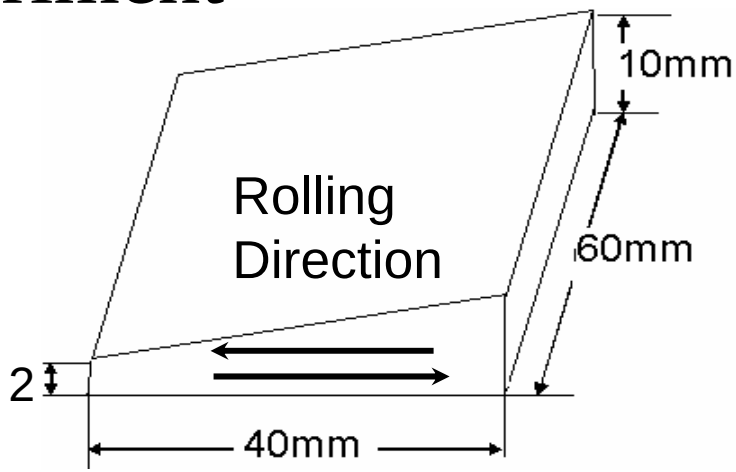


- <111> // ND texture is good for deep drawability for steels, also good for deep drawability for Nb (yes).
- Would understanding of cold rolling and recrystallization texture evolution for interstitial free (IF) or extra-low carbon steels be transferable to pure niobium?
- Different surface grain orientations etch differently, causing grain boundary ledges (no) that are centers for electron emission
- <100> // ND grains have lower work function for undesirable electron emission

H. Jiang, *et al.*, 2003 Particle Accelerator Conference, IEEE, p. 1359.

Can we control surface texture? Maybe…
Tapered Slab Rolling Experiment

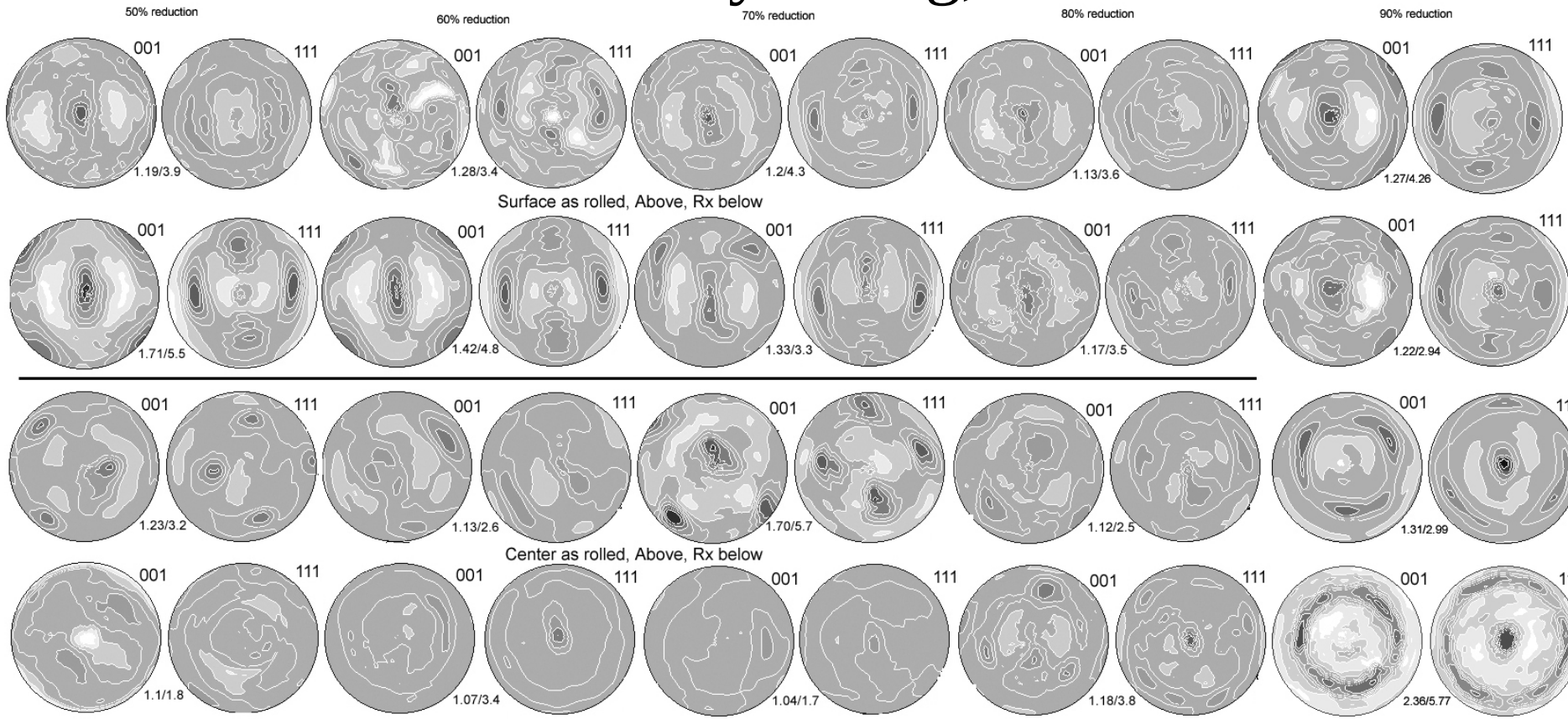
- As-received Nb (RRR=150) tapered specimens made from 12 mm plate
- Unidirectional path cold rolling
- Reversed path cold rolling
  - without lubrication at room temperature
- A strip was annealed for 1 hour in evacuated quartz tube
- Pole figures were measured from surface, interior of both rolled specimen and annealed specimens
- OIM data was collected for through thickness measurement



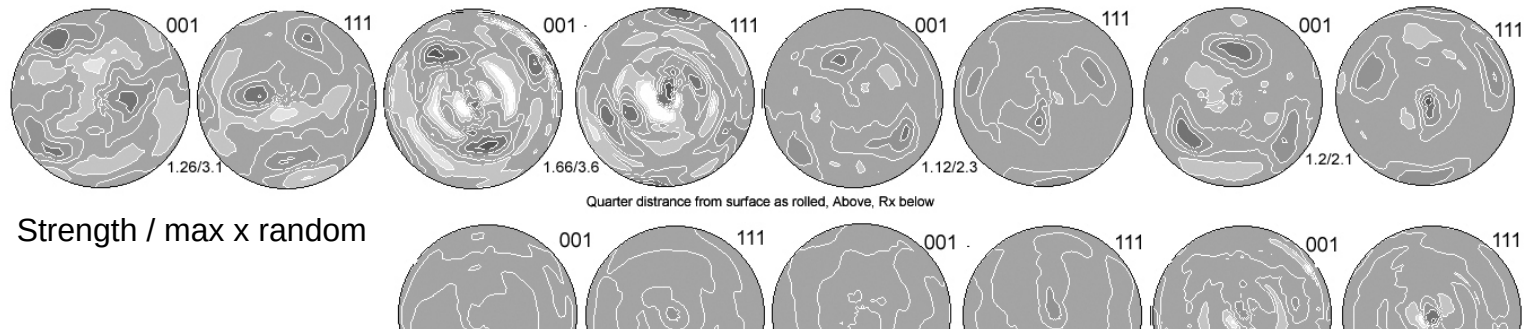
After rolling, sliced into strips

Lots of Data!! (unidirectional rolling)

Textures are not very strong, < 6 x random…



Rx anneal weakens center, strengthens surface <001> || ND ☹

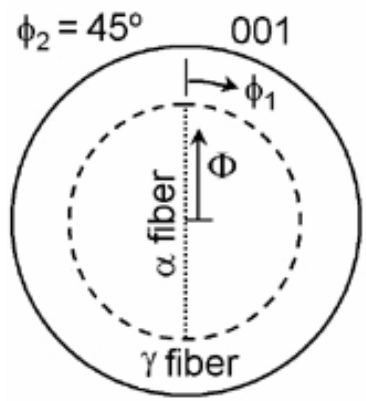


Strength / max x random

Initial rotated cube component in center was maintained up to 70% reduction

In Steels, most crystal orientations are in a particular COD section (ϕ_2= 45º) along α or γ fibers. In this same section, similar changes are observed in 80% rolled Nb,

but this is a minority of Nb crystal orientations.



In the ***center***,

After rolling, the α fiber deceased, γ fiber increased

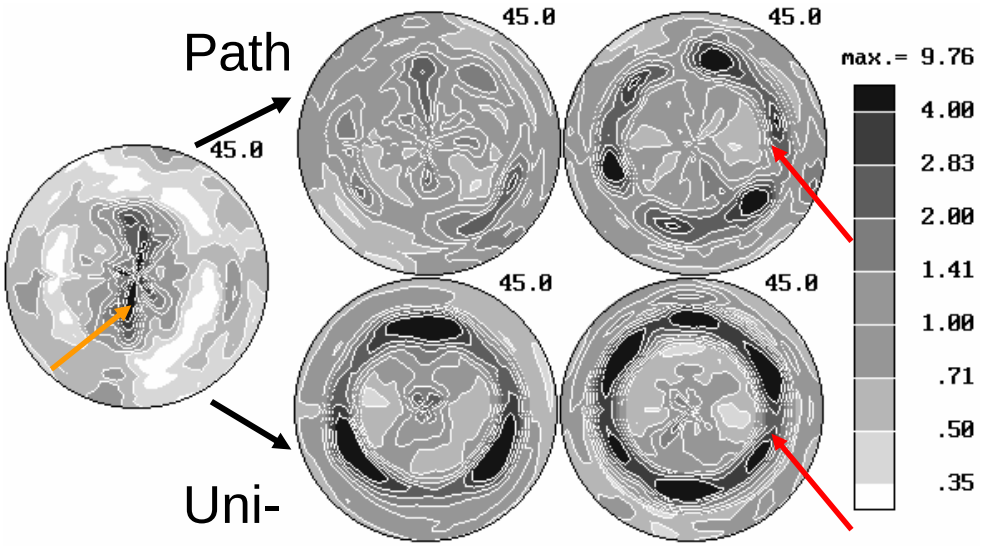
After annealing, the γ fiber becomes very strong

COD sections

Initial Rolled Annealed

Reversed Path

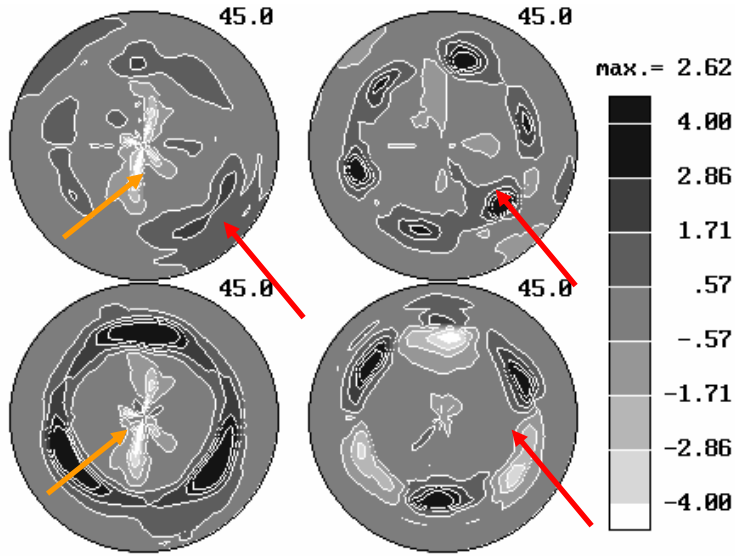
Uni-directional Path has stronger γ



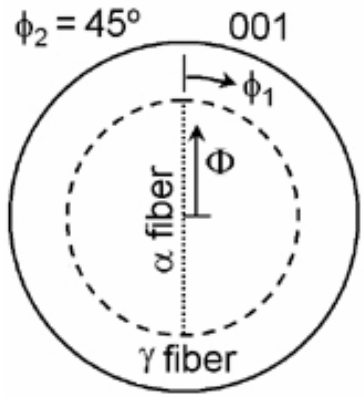
Difference from prior state

Rolled -Initial

Annealed -Rolled



On the surface, α, γ fibers in the (ϕ_2= 45º) COD section change ***less*** due to 80% rolling and annealing



After rolling, α fiber unchanged, slight γ fiber increase

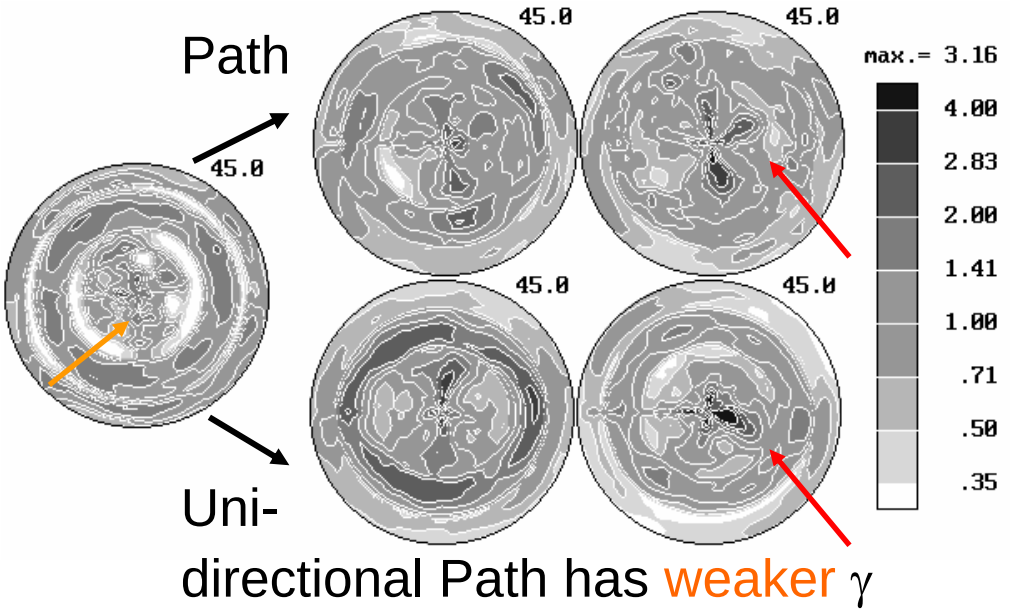
After annealing, the γ fiber weakened

COD sections

Initial Rolled Annealed

Reversed Path

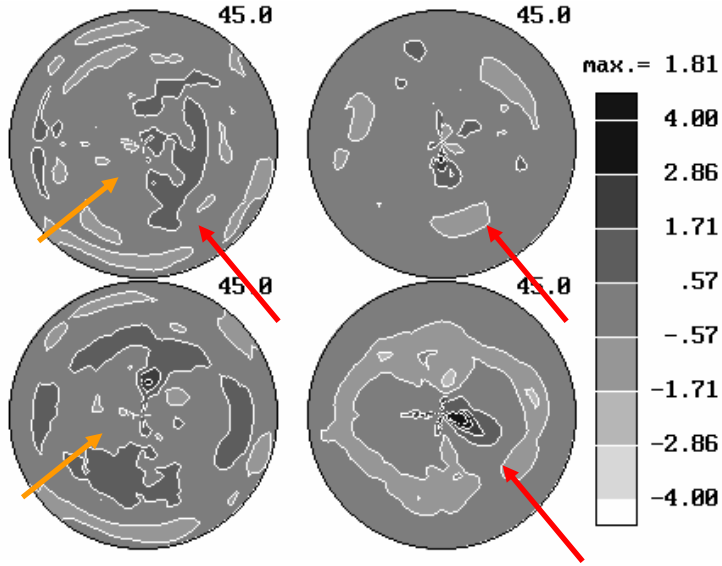
Uni-directional Path has weaker γ



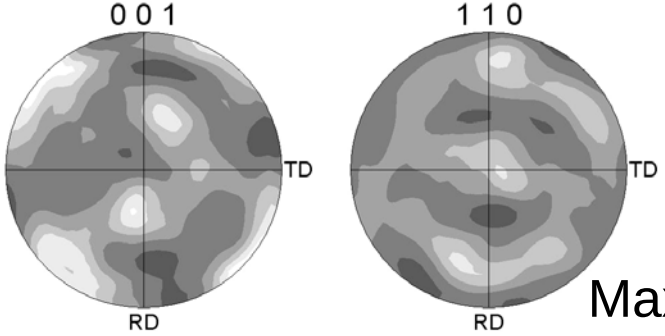
Difference from prior state

Rolled -Initial

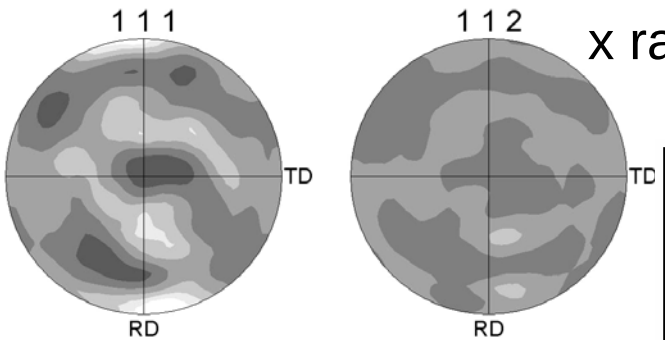
Annealed -Rolled

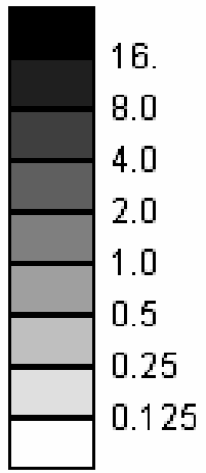


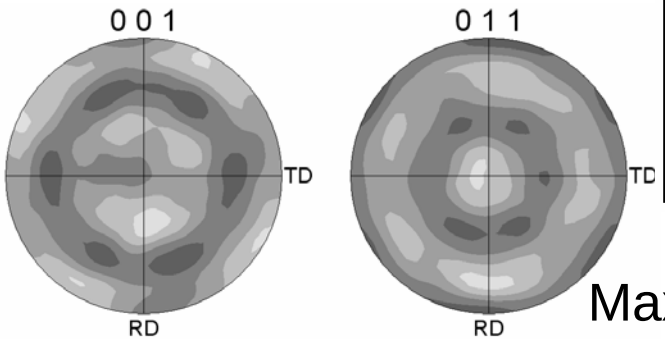
Processing path (80% reduction) affects texture!



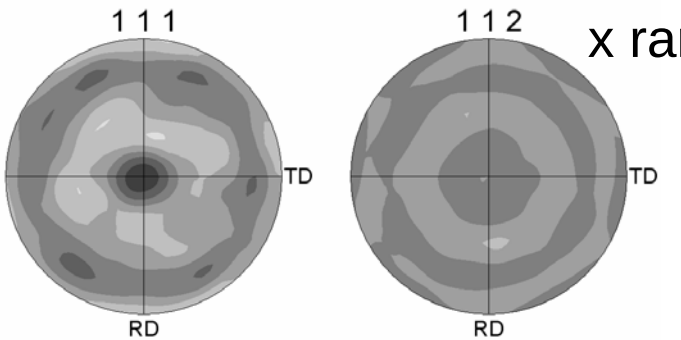
Max 3.4 x random



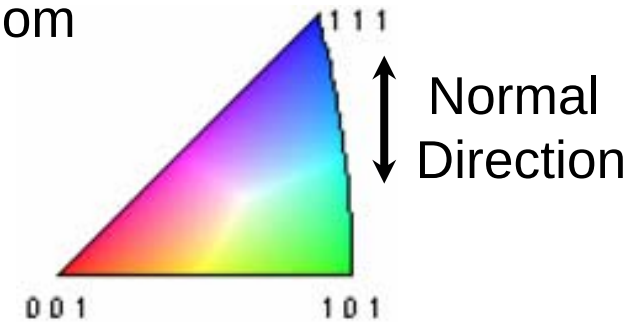




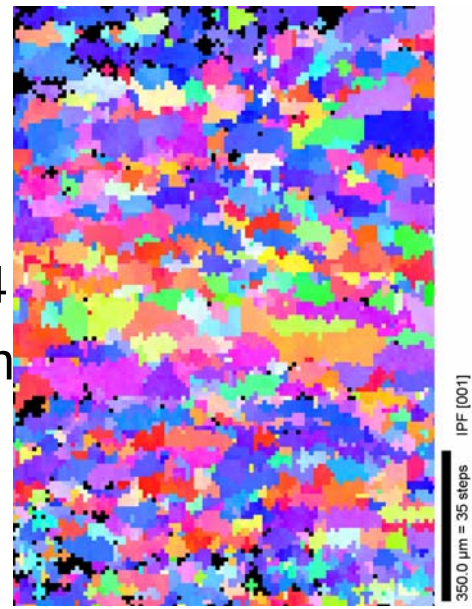
Max 7.7 x random



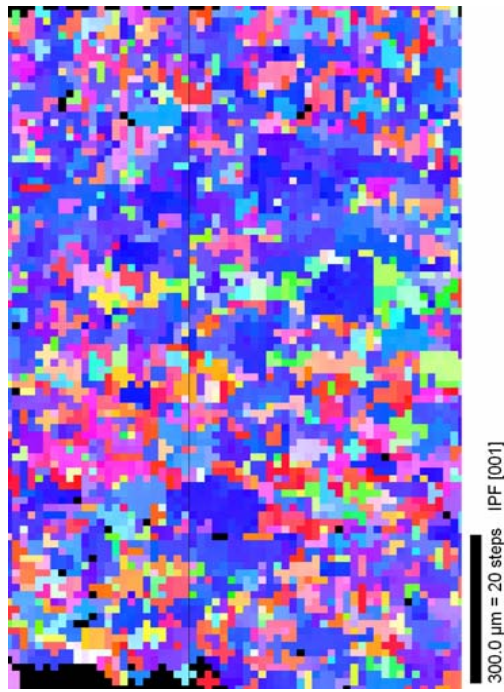
- Reversed Rolling has weaker texture, gradients in grain size, texture
- Unidirectional Rolling has stronger [111] texture, more uniform grain size, fewer gradients



1.4 mm



RD



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Continuing questions

- Are there processing paths to obtain best formability ***and*** surface property conditions?
- Are Nb welds dimensionally stable?
- Is Nb like steel or not?
- “Single crystal” cavities …
  - Will they be soft due to no grain boundaries?
  - Will they recrystallize inhomogeneously after forming and heat treatment?
  - Will they be dimensionally stable?